JPRS 76951

8 December 1980

Worldwide Report

NUCLEAR DEVELOPMENT AND PROLIFERATION

No. 73

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SWEDEN

NORWEGIAN ENGINEERS VISITING USSR: NUCLEAR POWER PLANTS AS SAFE AS THE WEST'S

Oslo AFTENPOSTEN in Norwegian 27 Oct 80 p 9

[Article by Georg Parmann: "Russian Nuclear Power Plants as Safe as the West's"]

[Text] There is no reason to believe that safety in Soviet nuclear power plants is poorer than in other countries. Chief Engineer Rolf Lingjaerde draws this conclusion in conversation with AFTENPOSTEN. He headed a Norwegian energy delegation which returned on Saturday from a 10-day visit to the Soviet Union. The delegation visited one of the largest nuclear power plants in the country, and had conversations, among others, with representatives of the State Committee for Science and Technology. Lingjaerde bases his conclusion on information the delegation obtained in inspections and meetings.

Doubt has existed, heretofore, on how safe the Soviet nuclear power plants really are. Among other things, we know that nuclear power plants on the Kola peninsula do not have safety containers of the type usual in the West. In addition, very limited information about safety in the Soviet power plants has been available in the West, which has made it difficult to gain a correct impression of safety equipment in the Soviet power plants. It is also known that the Russians have a somewhat different safety philosophy than the one common in the West.

"Some discrepancies in earlier impressions we had concerning Soviet nuclear power plants were cleared up for us. Experts we talked with also told us that a gradual development has been under way as concerns equipping the reactors with various types of safety features. We were told that the small reactors are equipped with safety systems common in other reactor installations of this type. Among other things, they have the same type of cooling-down systems and a form of safety containers around the reactor systems," says Lingjaerde.

The Newest Reactor Type

The delegation was also shown the newest Soviet reactor type, of 1,000 megawatts. It is being put into operation at the nuclear power installation in Novoronoezh. Our impression was that this power plant is built up in the same way as such plants are in the West, and will be operated in similar

conditions. At that power plant the delegation was shown a training center for reactor operators, which impressed us greatly. The center is used for training reactor operators from the countries where the Soviet Union has delivered nuclear power plants, East Germany and Finland among them.

Four of the delegates also had the opportunity to visit the famous Kurtshatov Institute in Moscow, where fusion research is carried on. It is among the most advanced institutes in this field in the world, and there the Russians cooperate with researchers from Great Britain and some Eastern European countries, among others.

"We were shown the fusion section and the great experimental installations, which impressed us very much. Now under construction is a new experimental installation based upon the so-called Tokamak principle. With this new installation, which, we were told, will be in operation by 1983-1984, the researchers will be able to get a significant step closer to the great breakthrough expected in fusion research--to get a controlled nuclear reaction started. Even though this institute is very advanced, there was no optimism concerning speedy use of fusion in energy production. It was indicated that that was something far in the future," says Lingjaerde.

First Hydroelectric Energy

The energy delegation, which consisted of representatives of the Norwegian Watercourse and Electric Power Administration and the Norwegian Energy Society, saw also a large hydroelectric plant being completed and a large thermoelectric power plant. Director Sigurd Aelefjaer of the state power plants says that the most interesting feature of these visits was the realization that the Russians are developing their energy supply according to the same philosophy advocated by energy professionals in Norway, meaning that they wish to develop hydroelectric energy to the extent possible and next supplement it by nuclear energy.

"Concerning hydroelectric energy, the most interesting thing to see was the dam work at the Inguri plant. Here, dimensions are worked with far above what we are used to and with imposing machinery and equipment. Our impression of the electricity-producing parts of the plant, turbines and the like, was that our level is at least equal to what we saw," says Aaefjaer.

"The thermoelectric power plant we saw did not as far as we could see differ significantly from what we are used to in Europe. The only thing new was the cooling, done by means of air in large cooling towers. This was due to the minimal availability of water in the district where the plant was situated. This is a technique of no present interest to us. In the things we saw there was great differences in execution, in our opinion. Some things were of top quality, while others were less well done than what we would have considered judicious," says Aaefjaer.

"Our general impression of the visit is that the Norwegian delegation was taken care of in the best possible way. We were guided by three official representatives during the entire trip, in addition to a guide who spoke

Norwegian. Everything was arranged so that we would benefit as much as possible from the visits to the power plants. A main impression is also that the experts we met were very frank as concerns information at all levels. In addition to the representatives who accompanied the delegation on the whole trip, a number of local experts were available. Seen with Norwegian eyes, there were surprisingly few restrictions on photography.

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'PRAVDA' VIEWS FINNISH NUCLEAR POWER PROJECT

LD171105 Moscow PRAVDA in Russian 12 Nov 80 p 4

[Dispatch by correspondent Yu. Kuznetsov: "The Nuclear Power Station at Lovisa"]

[Excerpts] Lovisa-Helsinki, November--We were talking in the place where they work--in the turbine room and the concrete "housing" of the reactor of the nuclear power station not far from the Finnish town of Lovisa. For 3 years now its first 440,000-kilowatt power unit has been in operation here, and now--again with the aid of Soviet specialists and organizations--a second one has been installed.

When Lovisa-2 was being prepared to go on stream, I met with the managers of the firm (Imatran Voyma), which supplies 40-45 percent of all the electricity used in Finland. They noted the great significance of the construction of the nuclear power station for Finland, and spoke enthusiastically about the good prospects for Soviet-Finnish cooperation in this field.

"As you know, our country is poor in natural energy resources," remarked the firm's General Director (P. Alaeki). "Therefore we value highly the opportunity to develop cooperation with the Soviet Union in the energy sphere; this accords with the general course of development of Soviet-Finnish relations."

"Perhaps the nuclear power station in Lovisa could be called the most interesting cooperation project between our firm and Soviet organizations," said Director K. Numminen. "The first power unit, which has worked successfully for 3 years, has aided the growth of our authority in no small way--and also of the excellent reputation of your science and technology and your specialists here in Finland. We make no secret of the fact that we would now like to make use of the experience gained from the construction of the nuclear power station in Lovisa to implement joint Soviet-Finnish projects in third countries as well."

They do not separate cooperation with the Soviet Union in the energy sphere here from the successful development of trade, economic, scientific, technical and political ties between our states, their lasting importance and promising nature is noted. The Finns are aware that the course of maintaining friendly and good-neighborly relations with the Soviet Union, known here as "the Paasikivi-Kekkonen line," has secured and continues to secure for Finland strong positions in the world and the authority of a peace-loving sovereign state and provides a trustworthy partner for its economy, cooperation with whom does not depend on the zigzags of capitalist market conditions.

The nuclear power station at Lovisa has become a truly living and convincing example of the mutual advantageousness of this cooperation demonstrating the boundless possibilities which open up for people who wish to live in peace and friendship.

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TAIWAN TO INCREASE STOCKPILES OF IMPORTED URANIUM, COAL

Johannesburg THE STAR in English 27 Oct 80 p 32

[Text]

TAIPEI — A Taiwan company wants to guarantee its future needs through long-term contracts with a number of countries, led by South Africa, to build up a strategic stockpile of coal and uranium.

A Taipower official in Taipei told me the plan called for stockpiling of five months' normal supply of steaming coal (against one-and-a-half months at present and an increase in the uranium stockpile from two to three-and-a-half years.

"The fuels will be purchased diversely from a number of countries, and where possible will be on the basis of long-term contracts," he said.

South Africa will play a leading role, at least in uranium. The Taiwan company already has a 400-million dollar contract for the supply of four thousand tons of South African uranium ore between 1984 and 1990, and it is possible Taipower will go back to try and increase the amount as it reviews its growing needs.

This is part of the island's programme to diversify away from its traditional dependence on the United States.

Taipower plans to have a two-year supply of uranium fuel always stored in the country, with another 18 months guaranteed amount stored abroad, presumably by the supplying country.

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BRIEFS

NUCLEAR FUEL REPROCESSING--Tokyo, 21 Nov (KYODO)--South Korea has sounded out Japan about reprocessing its spent nuclear fuel in this country, a government source disclosed Friday. The source said Pak Kung-sik, a member of South Korea's Atomic Energy Commission, had asked Japanese officials whether Japan is ready to reprocess spent nuclear fuel from South Korea. Pak, who visited Japan to attend a joint Japanese-Korean seminar, made the inquiry when he met with four leading members of the Japan Atomic Energy Commission on November 18, according to the source. The source quoted the Korean official as saying he hoped Japan's reprocessing plans covered the requests from neighboring countries. South Korea earlier abandoned its effort to construct a reprocessing plant with the help of France because the United States had claimed that the plutonium produced in the reprocessing could be used for nuclear weapons. South Korea's first atomic power plant went into operation in 1978 and four other plants are under construction. It expects 44 plants to go into operation with a generating capacity of 72 million kw by the year 2000. A spent nuclear fuel reprocessing plant is operating at Tokai-Mura, Ibaraki Prefecture, and another plant is expected to be built by non-governmental organizations. [Text] [OW21137 [as printed] Tokyo KYODO in English 1255 GMT 21 Nov 80]

CSO: 5100

BRIEFS

URANIUM DELIVERY EXPEDITED--India has informed the U.S. government that it would not accept continuing delays and uncertainties in the supply of enriched uranium fuel for the Tarapore atomic plant as mutually agreed upon in 1963. Stating this in a written reply in the Rajya Sabha yesterday, Minister of State for Science and Technology C.P.N. Singh said the government has requested the United States to clear the second shipment of fuel for Tarapore without any further delay. Singh said the second consignment of 19.8 tons of fuel for the atomic reactor of Tarapore has become overdue. [Text] [BK210459 Delhi Domestic Service in English 0240 GMT 21 Nov 80]

HEAVY-WATER PRODUCTION PROBLEMS OVERCOME--Chairman of the Atomic Energy Commission Dr Sethna has said that a number of power stations using natural uranium with heavy water as a moderator are to be set up in the first phase of the country's nuclear program. He said the country has overcome the problem of producing heavy water and it is only a matter of time to produce the requisite quantity of heavy water for our power program. Dr Sethna was delivering the Sanjay Gandhi memorial lecture on energy strategy for the 80's organized by the development research group in New Delhi today. Dr Sethna said that the current indications are that the uranium resources in India can support a natural uranium reactor program of the order of 10,000 megawatts over its lifetime. [Excerpts] [BK201609 Delhi Domestic Service in English 1530 GMT 20 Nov 80]

NUCLEAR INDUSTRY SEALANTS--New Delhi, October 27--Sealants for the nuclear industry have been developed indigenously by the power projects engineering division (PPED) and the chemistry division of the Bhabha Atomic Research Centre. The process is now available with the National Chemical Laboratory, Pune, for commercial exploitation. The limited life of imposed sealants and the unreliability of supplies from abroad prompted BARC to embark on a programme for developing indigenous sealants with stringent specifications. For nuclear structures, polysulphide sealants have been chosen because of their excellent durability. They also have a very high degree of resistance to water, chemicals and heat coupled with a high life expectancy of about 20 years. [Text] [Bombay THE TIMES OF INDIA in English 28 Oct 80 p 9]

CSO: 5100

NUCLEAR SCIENCE INSTITUTE PURCHASES NEW ACCELERATOR

Radiation Leakage Minimized

Wellington THE EVENING POST in English 30 Sep 80 p 29

/Text/ The $250,000 nuclear accelerator to be installed next year at the Institute of Nuclear Science in Gracefield, Lower Hutt, will offer very little danger from radiation leakage according to Mr Graham McCallum.

"There is radiation during some experiments which could be dangerous, but even if you sit in front of an X-ray machine there is danger from radiation," he said.

"It has to be understood that almost everything is radioactive. Even people have a radioactive substance, carbon-40 inside them," he said.

"We will be producing radiation during some experiments and I could never say there will be no radiation leakage. The meaningful thing about radiation leakage in this situation is whether it's detrimental to health.

"There will be no problem in controlling radiation levels to those approaching normal levels."

The new accelerator, a Tandem van Degraaff capable of reaching 6,000,000 volts and doubling energy particles to reach 12,000,000 volts, will replace much of the work of an accelerator now in use which can only reach 3,000,000 volts, he said.

Although the accelerator is still waiting for shipment from Australia until next year much of the ancillary equipment has already been installed in a new building adjoining that housing the present accelerator.

The primary objective of the new accelerator is for use for a new type of carbon-dating technique which counts the number of carbon-14 atom levels to determine from their radioactivity when a living thing died, he said, something which is of great value to anthropologists and geologists.

As well it will be used for dating rock samples from a period of time which could previously not be dated because of inferior techniques, and to determine hydrogen concentrations for corrosion studies, he said.

Purchased From Australia

Wellington THE EVENING POST in English 21 Oct 80 p 40

/Photo caption; photo not reproduced/

/Text/

THE BUSINESS end of the DSIR's new $300,000 nuclear accelerator being inspected by two of the team of scientists working on its installation, Mr Graham McCallum (left) and Dr Murray Bartle.

The DSIR's Institute of Nuclear Sciences at Gracefield purchased the Tandem Van de Graaf accelerator from the Australian National University in Canberra. A new accelerator could have cost more than $2,000,000.

All the ancillary equipment, apart from the accelerator itself but including its massive 23 tonne pressure vessel which will be accommodated in a separate building yet to be constructed, has arrived.

Mr McCallum and Dr Bartle are in the "target area" where the experimental work with the accelerated particles will be conducted.

The 6,000,000-volt accelerator will greatly increase the range of work able to be done by the institute, particularly in determining the age of archaeological and mineral samples. It will also be invaluable in fields such as corrosion and sedimentation study.

The institute's present 3,000,000-volt accelerator will be retained as research programmes undertaken with these machines will be complementary.

The total cost of the accelerator and the new extension to house it is expected to be about $500,000.

It is hoped the accelerator will be ready for use during 1982.

CSO: 5100

SITE FOR NEW WATER GEL EXPLOSIVES PLANT APPROVED

Auckland THE NEW ZEALAND HERALD in English 24 Oct 80 p 1

/Excerpt/

A $1.7 million explosives factory will be built on an isolated 190-hectare site near the top of the Kaimai Ranges, about 20 kilometres from Tauranga.

Interim approval for the plant — which will produce water gel explosives — has been given by the No 4 division of the Planning Tribunal.

The factory will be put up by an American-based company, Du Pont New Zealand Ltd. A final decision on construction will be given in a month, after details of conditions governing the approval are settled.

The solicitor who appeared for the company before the tribunal, Mr H. S. Hancock, said from Wellington last night that the explosives will be used for a wide range of industrial purposes, such as forestry, [illegible], construction and mining.

The company plans to sell the explosives in New Zealand and to export them through the port of Tauranga to the South Pacific.

Mr Hancock said the site is near the top of the ranges, about 1.6 kilometres off the main road.

The chief inspector of explosives gave evidence that the company had met all the safety requirements, Mr Hancock said.

The reason for the location was that a certain amount of isolation was required.

Although the explosive had been imported in the past, it was still a comparatively new type.

Mr Hancock said it was extremely safe and that was the essential difference from glycerine-type explosives.

Mr Hancock could not say what amount would be produced or when the factory would start.

CSO: 5100

BRIEFS

NEW PINSTECH LABORATORY--The Pakistan Atomic Energy Commission has set up a new laboratory at its premier research centre PINSTECH, to prescribe maximum premissible limits of radioactive release at the SITE. According to the Commission sources the new laboratory called Derived Working Limits Laboratory (DWL) will be part of the Nuclear Safety and Licensing Division at the headquarters. [Text] [Karachi DAWN in English 12 Nov 80 p 8]

CSO: 5100

BRIEFS

THORIUM DISCOVERY--Speaking at the Education Committee of the Legislative Yuan on 13 November, Cheng Chen-hua, secretary general of the Atomic Energy Commission under the Executive Yuan, said that a small amount of thorium has been discovered on the west coast of Taiwan. Because of the complicated procedure to process the deposit, our country is still unable to use it. He said: Our country does not have uranium deposits but can extract thorium from the deposits and use it as a nuclear energy source. Secretary General Cheng also said: Based on the long-term contract signed between our country and South Africa, there will be no shortage of uranium in the coming 10 to 20 years. [Text] [OW210944 Taipei CHUNG YANG JIH PAO in Chinese 14 Nov 80 p 2]

URANIUM EXTRACTION BREAKTHROUGH--Taipei, 22 Nov (CNA)--The Institute of Nuclear Energy Research has achieved a breakthrough in extracting uranium from phosphoric acid, a spokesman confirmed. It is now seeking a worldwide patent. The institute, an agency under the Executive Yuan, is now capable of producing 10 tons of uranium a year, as well as 2.7 tons of monazite. It is able to produce uranium oxide that is up to the required standards. It has completed a factory in June which is capable of turning out 10 tons of uranium a year. Since industrial phosphoric acid contains as much as 100 ppm of uranium, the institute is planning to cooperate with the China Phosphate Industries Corp in extracting uranium from phosphoric acid. The institute said monazite sand is the only raw resource available in Taiwan that contains uranium. Thorium, which is contained in monazite, is also a useful industrial material. It has built an experimental factory capable of extracting 2.7 tons of monazite from monazite sand a year, which in turn can be used to extract thorium oxide. [Text] [OW221137 Taipei CNA in English 0942 GMT 22 Nov 80]

CSO: 5100

PLANS TO DOUBLE URANIUM INDUSTRIAL PRODUCTION ANNOUNCED

La Paz PRESENCIA in Spanish 6 Nov 80 p 8

[Text] COBOEN [Bolivian Nuclear Energy Commission] is planning an investment that will double the annual production of "yellow coke" uranium concentrates at the Cotaje Metallurgical Complex (Potosi).

Estimated annual production at the Cotaje mine is about 4,000 kilos of uranium concentrates.

Capt Edgar Ampuero, executive director of COBOEN, gave this information to PRESENCIA.

COBOEN added new technology and equipment to the uranium concentrate plant so that it passes from the pilot level it was at to a semi-industrial exploitation of uranium concentrates.

The expansion of the Cotaje plant was officially inaugurated in the second half of September.

Manufactured products for peaceful use and fuels for nuclear reactors and nuclear weapons can be obtained from "yellow coke."

The average cost of a pure kilo of uranium concentrates is $100.

The annual production of 4,000 kilos of uranium concentrates is the result of processing 20,000 kilos (20 tons) of ore.

Reserves

The mineral reserves in Cotaje total 70,000 tons with an average content of 0.0516 percent.

Of the 70,000 tons of ore, 40,000 tons are proven reserves and the remaining 30,000 are probable.

The proven reserves were verified by the aboveground method. The probable reserves would be defined by underground analyses and projects.

COBOEN plans exploitation of 50 tons of ore per day.

Cotaje is the first uranium mine in Bolivia. It could generate important resources to sustain nuclear research.

After a complicated technological process, a 60-percent uranium concentrate, considered commercial grade, is obtained.

The aboveground ore is stacked in piles of 2,000 tons each.

These piles are subjected to treatment with a solution composed of water, sulfuric acid (reagent) and manganese dioxide (oxidizer). This produces a liquid with a high uranium content; this process is known as lixiviation.

The second stage of recovery consists of elimination of a number of impurities, concentration, filtration and drying in order to finally obtain commercial uranium concentrate in the form of a powder.

Exploration

According to preliminary studies, it is estimated that Bolivia has 700,000 square kilometers with probable commercial-grade uranium. In 20 years, COBOEN itself has explored 20,000 kilometers, barely 3 percent of the total.

The executive director of COBOEN stated that the admission of foreign companies to invest risk capital has become necessary. Within 5 years, all national territory with probable uranium reserves can be explored.

He said that any contract signed with foreign enterprises "will preserve national sovereignty over all else, discarding the possibility of dealing with so-called transnational or multinational enterprises."

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CCEN PLANS TO RECOVER URANIUM FROM COPPER MINING PROCESS

Santiago EL MERCURIO in Spanish 24 Oct 80 p 1

[Text] Chile is capable of recovering between 40 and 60 tons of uranium annually from water used in the leaching of copper ore, Col Romualdo Pizarro, chairman of the Chilean Nuclear Energy Commission, stated yesterday during a meeting held at the commission's offices in celebration of its 15th anniversary.

He said that it is highly possible that a uranium-recovery plant will be built at Chuquicamata in 1981. Concerning this, he noted that the feasibility study carried out jointly with CODELCO [Copper Corporation] has already been approved by ODEPLAN [National Planning Office]. "We only need a decision to be made to give the go-ahead," he stated.

The plant will be capable of starting operations within the next 2 years. The Chilean Nuclear Energy Commission has drawn up various plans; they include the "National Radioactive Resources Plan" and the "Plan to Give Chile a Uranium Capability."

Concerning nuclear medicine, it was announced that Latin-American experts, acting with the advice of American professors, are concluding agreements for the provision of the most advanced technology in this field. Colonel Pizarro particularly mentioned diagnosis and radiotherapy in this sphere of medicine.

"Nationwide programs have been developed jointly with the National Health Service, requiring the establishment of pilot clinics engaged in the two activities. In Santiago, professionals were trained through the University of Chile at the Jose Joaquin Aguirre Hospital in preparation for the establishment of clinics in Antofagasta and Valdivia, which are operating independently," Colonel Pizarro noted.

Also present at the gathering were Col Juan Mir Dupouy, the director of the commission, and Lt Col Victor Aguilera Acevedo, the technical secretary.

During the conference, the subject of radiotherapy was discussed, and reference was made to the agreement for cooperation signed when Joao B. Figueiredo, the president of Brazil, visited Chile. Brazil has an ambitious nuclear program and the facilities needed for the training of Chilean personnel.

Research Reactors

Colonel Pizarro said that there are two research reactors and that a technical research plan was being drawn up for the establishment of the country's first nuclear center. However, fulfillment of this plan has been postponed until 1985.

Regarding the use of nuclear energy in place of energy sources now in use, he stated that by 1985 this source should meet 5 percent of the total worldwide demand and that by 2000 it should meet 30 percent of it.

In response to speculation that radioactive fallout from atmospheric tests conducted by China would reach the American continent, the colonel indicated that a network to monitor radioactive pollution had been set up. This system, consisting of stations at nine points in the country, makes it possible to analyze--on site--water, food and scattered dust.

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CSO: 5100

ARMSCOR CHAIRMAN: NUCLEAR CAPABILITY ONLY FOR PEACEFUL USE

Johannesburg THE CITIZEN in English 13 Nov 80 p 2

[Text] No country in Africa had a nuclear capability to his knowledge and South Africa's capability in this sphere was restricted to the peaceful use of nuclear power, Commandant Piet Marais, chairman of Armscor, said yesterday.

Answering questions, Cmdt Marais said it was difficult to judge whether any African country would be given a nuclear capability by an outside power. This possibility would depend on political developments in many parts of the world.

It was difficult to imagine any country in Africa being given a nuclear weapon to use at its own discretion, judged in the light of steps being taken by the United States and the Soviet Union to conclude the strategic arms limitation treaty. However, it was impossible to say that this would never happen.--Sapa

CSO: 5100

ATOMIC ENERGY RESEARCH IN BELORUSSIA

Minsk PROMYSHLENNOST' BELORUSSII in Russian No 9, Sep 80 pp 55-57

[Article by V. Nesterenko, Director of the AN BSSR Atomic Energy Institute, and A. Deveyno, laboratory chief and Candidate of Technical Sciences: "The Peaceful Atom"]

[Text] As is generally known, the first atomic reactor in our republic was built and put into operation not far from Minsk in 1962. Nuclear reaction was placed at the service of Belorussian science for the first time. Soon after this the team of young scientist enthusiasts proposed original subjects for investigation which became the basis for the creation in 1965 of the academic Institute of Atomic Energy. The main aim of its activities is the solution of one of the major contemporary problems--the creation of fundamentally new AES's [atomic electric power stations]. The entire course of energy development, particularly the shortage of traditional mineral fuel which is now becoming evident, has dictated this.

New energy sources have special significance in our republic because our fuel energy balance is very strained. The fact is that about 72 percent of our energy resources come from far away. It is economically unwise to plan the further development of the Belorussian power system on organic fuel thermal electric power stations. The way out of this situation is the construction of AES's and heat supply sources. The first step in this direction will be the construction in the 11th and 12th five-year plans of a powerful ATETS [atomic thermal electric power plant]. They intend to use AST's [atomic heat supply stations] for the centralized heating systems of the republic's major cities. They can be located very close to the cities (within 2-3 kilometers) which significantly decreases capital expenditures for heating network construction.

The Institute of Atomic Energy is working closely with Belglavenergo [Belorussian Main Power Supply Administration] and the Belorussian branch of VNIIPIenergoprom [All-Union Scientific Research and Planning Institute of the Power Engineering Industry] in solving these problems. However, our team's main efforts have been directed at solving more long-range tasks. It is known, for example, that an overwhelming majority of the AES's now being created are equipped with thermal (slow) breeder reactors. The next stage in the development of AES's is the creation and assimilation of fast breeder reactors. Work on this complex problem occupies an important place in the activities of the institute's collective.

The following is at the core of the problem. Almost all modern AES's with thermal breeder reactors use uranium-235, which is scarce, as nuclear fuel. It is impossible to effectively use the isotope of uranium-238, which is significantly more plentiful in nature, in thermal breeder reactors. Therefore the general direction in the future development of nuclear energy is the creation of fast breeder reactors permitting the use, specifically, of natural uranium-238. During its retreatment in such a reactor, in addition to the generation of energy, a new fuel--plutonium-239 is built up of which, because of the nuclear reaction, even more is obtained than was used for the initial charging. The accumulated plutonium-239, in turn, can be used as a fuel in second generation reactors. Thus, the technical mastery of fast breeder reactors, thanks to the possibility of using the very plentiful uranium-238 and the production of plutonium-239, significantly(by 30-40 times) increases the potential nuclear fuel resources and permits the broad development of atomic energy.

It is necessary to solve a number of fundamentally new problems during the development and creation of fast breeder reactor AES's. One of them is the selection of a heat carrier--a substance which takes in heat escaping as a result of atomic fuel combustion and carries this heat into the heat exchanger or turbine. Water, which works well in thermal breeders, cannot play this role in fast breeder reactors because of physical reasons. Therefore, liquid sodium is used as a heat carrier in first generation fast breeder reactors(for example, at the Shevchenkovskaya AES and the third power block of the Beloyarskaya AES). However, at the same time the transfer of heat from the nuclear reactor to the steam turbine is difficult and the problem of the reliability of the steam generators arises. To avoid these shortcomings, they are now trying to use helium, carbon dioxide, etc. as a heat carrier.

The Belorussian scientists have gone along another path. For a number of years they have been successfully exploring a fundamentally new heat carrier--dissociating gases. A readily-available, inexpensive chemical product--nitrogen tetroxide, has been chosen. A molecule of this substance, during heating, is broken down (dissociated) into simpler molecules. It takes in sufficient heat at the same time. During cooling the molecules are again united and discharge heat. Thus, dissociating gases are capable of carrying more energy than other heat carriers which permits them, as demonstrated by the institute's work, to make AES heat exchangers which are compact and have less metallic content. Dissociating gas turbines are several times smaller than turbines of corresponding capacity which operate on water vapor. Besides this, a gas heat carrier has a very low induced radioactivity and can enter directly into the turbine from the reactor. This will allow one, during the creation of an electric power station, to manage with one heat transfer circuit instead of the two and three circuits which are now used in AES's. This results in a decrease in capital expenditures for construction.

The institute's collective, as a result of many years of theoretical and experimental study, has elaborated a theory for the use of dissociating gases in atomic power engineering. It has been expounded in 30 monographs and numerous articles, accounts, and scientific reports. The project development of AES's with the new heat carrier has been carried out on the basis of this theory under the scientific leadership and with the participation of the institute in close cooperation with a number of the country's scientific and planning organizations. Specifically, as an intermediate stage on the path toward the planning and construction of large industrial AES's of this type, a draft project of a 300,000 kilowatt experimental industrial

electric power station with a fast breeder reactor and a BRIG-300 dissociating heat carrier was developed. Specialists from Moscow and Leningrad, and from the academies of science of the Ukraine, Moldavia, and Lithuania are actively participating with specialists of our institute in the further development of it already at the technical project level. Friends from Poland, Bulgaria, and Hungary are helping us within the framework of CEMA to create a BRIG-300 AES.

By the way, the new heat carrier studied at the Institute of Atomic Energy of the BSSR Academy of Sciences can also be used in other sectors of industry not directly connected with power engineering. Its introduction saved more than 50 million rubles in 1979-80 alone.

A powerful experimental facility, unique in its makeup, was created at the institute to provide scientific and planning development in the area of creating fundamentally new fast breeder reactor AES's. Large-scale research stands, physical reactors, and a radiochemical laboratory have been constructed and are operating on a dissociating heat carrier and the capacity of the first Belorussian atomic reactor IRT[expansion unknown] has been increased from 2,000 to 5,000 kilowatts. An experimental production SKB[special design office], created in 1973, assists in substantially increasing the effectiveness of our work and in speeding up the introduction of research results into the national economy. One can say with certainty that the experimental production institute-SKB system proposed by the president of the Belorussian SSR Academy of Sciences, academician of the Belorussian SSR Academy of Sciences N. A. Borisevich, representing a single, large, scientific-industrial complex, has provided a very fruitful combination of thorough research, scientific and technical solutions and, finally, work on creating AES projects and manufacturing individual equipment units and elements in metal.

The institute is not avoiding today's problems by resolving the long-term atomic power engineering problems. All of the work on introducing gamma-radiation into the technological processes, carried out on a UGU-420 special-purpose gamma-ray source operating on radioactive cobalt-60, deserves attention in the plan. This source was developed and created by the staff members of the institute. Its radiation power is equal to a radiation power of 420 kilograms of radium. Some of the work conducted on this source is for the national economy of the country.

The scientists of the institute together with their colleagues from a number of other NII's[scientific research institutes] of the country and the Belorussian NII of Soil Science and Agricultural Chemistry, and Belgiprobiosintez[Belorussian State Planning Institute of Biosynthesis], in cooperation with the collectives of the Nesvizhskiy Fodder Biomycin Plant and the production association Soyuzbakpreparat [All-Union Association for Bacteriological Compounds], have developed the technology of obtaining from peat a new bacterial fertilizer with nitrogen-acquiring bacteria--rhizotorphine. A radiation sterilization method has been used in its production. Gamma radiation, as much research and experience has shown, destroys the microflora of the peat and permits the obtaining of high-quality rhizotorphine free of foreign micro-organisms. The subsequent intentional injection of nitrogen-acquiring bacteria into the sterile peat creates a new effective fertilizer. It is interesting to note that 200 grams of rhizotorphine per hectare are required to cultivate bean seeds before sowing them. Moreover, there is a 16 to 37 percent increase in the Belorussian harvest.

Most of the rhizotorphine sterilization work is now conducted on a gamma-ray source at the Institute of Atomic Energy of the Belorussian SSR Academy of Sciences, and the injection of nitrogen-acquiring bacteria is done at the Nesvizhskiy Biomycin Plant. Specialists have calculated that the savings from using this innovation to stimulate soy bean growth by utilizing a radioactive sterilization method exceeded six million rubles throughout the country during the years 1976-79. And these are only the first steps in the introduction of the new bacterial fertilizer into agricultural production.

The institute's collective overfulfilled its socialist obligations for rhizotorphine production in 1979-80. More than half a million hectares of bean crops have now been sown with seeds cultivated by it. The construction of a plant for the production of this valuable fertilizer has been started in Nesvizhe.

Research on the radiochemical modification of concretes, specifically on the production of decorative concrete polymers, conducted on a UGU-420 multipurpose gamma-ray source, is of great practical interest. These can be obtained by soaking the surface layer of a solidified concrete matrix with a monomer and polymerizing it by irradiation with ionizing radiation. Mineral dyes are introduced into the concrete mix before it hardens. Then the material obtained is polished and buffed by the usual method. Decorative concrete polymer matches the outward appearance of marble in its broad range of coloring and finish. Its mechanical strength is 3-4 times higher compared with ordinary concrete, and it withstands 300 cycles of thawing-freezing (marble according to GOST [all-union state standard] withstands 30 cycles).

Decorative concrete polymers can be used for sealing the outer walls of buildings, underground passages, monuments, etc. An experimental industrial batch of this building material was turned over to the Grodnenskiy Oblispolkom for full-scale testing. An overall work program for this task has been worked out and is being examined.

Several studies, conducted on a UGU-420 multipurpose gamma-ray source, have already been completed and have led to the introduction of specific innovations. Thus, based on a process developed at the institute for the radiation gamma-sterilization of medical articles, a republic radiation sterilization center was created and put into operation at the 5th Clinical Hospital of Minsk in 1978. The institute in its order turned over an appropriate irradiator and trained personnel to work on it.

During its 15 years of operation, the institute has grown from a relatively small collective to a large-scale organization with a staff of over 1,500 people. Eight doctors and 74 candidates of science direct the scientific work and 50 graduate students are training for the candidate degree.

The experimental facility is now being further broadened and upgraded and the working and living conditions of the collective are being improved. A plan, going up to [illegible], for the social and industrial development of the institute and the settlement of Sosna, where its staff members mainly live, has been elaborated and approved. The population of this settlement is about 2,000 today. A high school was opened here recently and a new comfortable dining room was turned over to the institute for use.

The institute's collective is full of energy and creative plans. This permits us to say with confidence that it will successfully solve those problems facing it concerning the development of atomic energy and the introduction of nuclear radiation into the national economy.

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POWER FIRM DISCOVERS DANGEROUS RADIOACTIVITY LEVELS

Helsinki UUSI SUOMI in Finnish 21 Oct 80 p 6

[Article: "Deadly Radiation Reading: Mischief in Loviisa's Nuclear Power Plant"]

[Text] A very high, deadly radiation reading was noticed on the radiation dosage meter of a worker at Imatra Power Company's Loviisa nuclear power plant.

But medical examinations of the worker have shown that the person did not receive radioactive rays. The high reading of the meter is suspected of being intentional mischief.

Radiation safety inspector Olli Vilkamo says that an abnormal reading was noticed on one of the "dosimeters" or radiation dosage meters. The meter showed 30 times the normal values, on the basis of which the person wearing the meter was assumed to have received a very large amount of radiation in his/her body.

"The worker was sent immediately for a thorough medical examination. But no kind of radiation or chromosome damage was found."

The dosimeter is used in the radiation-control area of the nuclear power plant. The device is an individual one, and it is attached during working time to the front of the protective clothing. At other times the meter is kept on the so-called "meter board," next to a public walkway.

Bjorn Wahlstrom, radiation safety head at the Loviisa nuclear power plant, says that a few theories have already been eliminated by the studies made.

"There is no technical defect in the radiation dosage meter. Nor was there anything special in the way the device was used. For example, it didn't go through a washing machine along with the dirty overalls. The only theory left is that someone intentionally set the meter to a point that showed high radioactivity.

Studies to clear up the matter are in progress. The Loviisa police have interviewed many of Imatra Power's personnel already.

"Peculiar Event"

Klaus Raninen, press secretary of Imatra Power, considers the event to be a peculiar one, one that needs to be explained thoroughly.

"The reading on the meter was so high that anyone at the receiving end of that much radiation would have died immediately. The meter's reading was quite impossible."

The event was the first of its kind. In the opinion of press secretary Raninen, it must also be the last. If the deed was intentional, care must be taken that a similar event not be allowed to happen again.

"If the event that happened at the Loviisa power plant was an intentional act, it is clear that the guilty party belongs to the power plant's own personnel. No outsiders are allowed in the area."

Imatra Power has recently proposed that a paragraph be added to the nuclear power law now being drafted on the basis of which the background of workers in atomic power plants could be investigated. The demand has been supported on the basis of safety in the plants.

"The Loviisa event had no effect on this demand, since it was made much earlier," says Klaus Raninen.

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BRIEFS

LOVIISA 2 BEGINS OPERATING--Loviisa (HS), Loviisa's second power unit was placed in operation Friday evening. The process that has preceded the start-up of Loviisa 2 has been long and expensive for Imatra Power. Construction work on the plant began in August 1972. According to the original schedule the reactor should have gone critical already in October 1977. Commercial operation of the plant should have been achieved in April 1978. Delay in important components, defects in the corrosion-resistance layer of the pressure vessel, and study of defects in the boiler delayed placing the plant in operation. In preparing Loviisa 2 for starting up, many defects were found in the electric motors of the main circulating pumps and in some safety vents. Loviisa 2's reactor was loaded with nuclear fuel already last May. But defects in the boiler delayed operation. The nuclear reactor was kept at a subcritical level during the 6-month interruption with a boron solution. Dilution of the boron solution was started early Friday morning. At first Loviisa 2's reactor will be used at only 2 percent of full power. The power will be raised gradually during the test period. If everything goes well, it is possible that Loviisa 2 will still produce electricity during October. It is intended that the plant will be connected to the national network around the end of the year. [Excerpts] [Helsinki HELSINGIN SANOMAT in Finnish 18 Oct 80 p 13] 9611

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COMMENTS ON NEW URANIUM ENRICHMENT PROCESS

Paris REVUE GENERALE NUCLEAIRE in French Jul-Aug 80 pp 358-359

[Article by Jean-Hubert Coates]

[Text] In an article dealing with the isotopic enrichment of uranium which was published in the NOTES D'INFORMATION of the AEC [Atomic Energy Commission] (issue No 6, 1980), Jean-Hubert Coates, assistant to the director of the AEC Department of Research on Isotopic Separation and of Chemistry and Physics, describes more particularly the methods of enrichment by chemical exchange reaction and talks about the procedure perfected by the commission. On this subject, he writes:

"The chemical exchange methods of separation were discovered in 1934 by Nobel Prize winner H. C. Urey. These methods were extensively used to separate the isotopes of light elements, such as deuterium and lithium, before they were considered for the separation of uranium isotopes.

"The principle of this operation depends on the small differences found in the kinetic of reaction of the isotopes to be separated.

"The rate of separation varies depending on the components which are present but it is unusually low, less than 10^{-3}, and the first requirement is to select components producing an isotopic effect as high as possible. This is not the only requirement. There will also have to be successive points of equilibrium between the components to multiply the basic enrichment effect. In practice, this is achieved by selectively distributing the two components in two phases which do not mix and can be liquid, gaseous or solid.

"Since the primary enrichment is weak, one will have to go through many phases of equilibrium before reaching a significant point of enrichment; this is called 'going into a cascade.'

"This method has not been used commercially as yet but the AEC has been developing it for more than 10 years. Over that period, almost every technical problem has been solved including the question of industrial development research on the choice of technical methods that should be used.

"In general terms, commercial plants using this procedure to feed a system of reactors operated by water and enriched uranium will consist of several parallel

modules with an annual capacity of around 200,000 UTS [expansion unknown] per unit. Each module operates independently and can enrich the uranium fed into it by about 3 percent of uranium-235 while the rejection rate can be adjusted to any desired value varying between 0.13 and 0.30 percent.

"It is now believed that plants with between 1 and 20 modules, in other words, plants with an annual volume of between 0.2 million and 4 million UTS can be quite competitive.

"It should take 6 years to build a plant where uranium is enriched by the chemical exchange method with a standard capacity of 3 million UTS.

"It takes considerably longer to achieve an isotopic equilibrium in plants using the chemical enriching method than in plants using other methods. For instance, it should take 15 months to reach the last stage of the cascade where the normal commercial content of 3 percent is reached. Since it should take around 35 months from the time when construction work starts until the modules go into operation, one can see that it will take 50 months from the time when the plant starts to be built until the moment when commercial production begins.

"Finally, the modular nature of these installations lends itself more than adequately to subsequent expansion. Although the production of components is a repetitive process, they are only medium-sized series and not very large ones which would require a high degree of automation in the production lines. Furthermore, the methods utilized are fairly classical ones. They can be introduced without difficulty in the industrial infrastructure of a country and do not cause any serious reconversion problem when discontinued."

In the same article, J.-H. Coates also compared the technical methods of isotope separation being developed throughout the world. His analysis results in the following table:

	Gaseous diffusion		Chemical exchange	Centrifugation	Laser
	current	advanced			
Stage of progress	industrially tested procedure	new concept to be developed	preindustrial stage (EAC) laboratory (Japan, USA)	industrial stage (Urenco) preindustrial stage (Japan, USA)	laboratory stage
Results obtained: -technically -economically	 excellent very good	 excellent to be confirmed	 good good	 good mediocre	 uncertain uncertain
Potential of improvement	20 percent		probable	probable	perhaps exceptional
Proliferating nature	medium	medium	very low	high	high
Countries possessing it	USA France	France	France Japan	Troika (UK, N. FRG) USA, Japan	USA USSR?

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PROCELLA-3 CODE FOR HWR LATTICE CELL CALCULATIONS

Milan ENERGIA NUCLEARE in English Apr-May 80, pp 210-219

[Article by R. Berti and G. Pierini of CISE-Segrate (Milano): "The PROCELLA-3 Code for HWR Lattice Calculations"]

[Text]

ABSTRACT *PROCELLA-3 is a code for HWR lattice cell calculations on a wide range of reactor operating conditions. Features of the code are: accurate prediction of cell parameters, use of physical models without correlations, fast calculations. This article outlines the lattice physics model embodied in PROCELLA-3 and compares some code predictions against the relevant experimental results.*

1. INTRODUCTION

The CIRENE reactor concept [1] was originated in the early sixties at CISE, where it was also developed over quite a few years. Basic features of this pressure tube reactor are the use of heavy water as moderator, natural uranium dioxide as fuel, boiling light water as coolant.

The development of the CIRENE reactor concept was accompanied by a wide research activity in reactor physics and related computational techniques. The results of such activities are now properly embodied in a set of computer codes, which permit reliable calculations of physical parameters and give guidelines for core design of heavy water moderated reactors.

This article outlines the lattice physics embodied in the PROCELLA code series, and compares the model predictions against the experimental results.

The standard lattice physics code PROCELLA [2] was developed first in 1967 and subsequently was subjected to some revision [3]. A cell burn-up code, named PROCIONE [4], which combines PROCELLA and the fuel burn-up equations, provided irradiation-dependent cell parameters to be used in core analysis calculations. An improved burn-up lattice physics code, named PSYCHE [5] and containing few innovations with respect to PROCELLA and PROCIONE, was developed in 1970 and subsequently updated.

More recently, theoretical developments and design requirements originated a quite different version of PSYCHE: this lastly-generated code will be referred to as PROCELLA-3. No further development is contemplated and henceforth PROCELLA-3 will be used throughout to provide cell parameters for survey and design calculations of HWR's.

(*) CNEN is gratefully acknowledged for having granted permission to publish this work, which was performed in the frame of the CNEN-CISE CIRENE AG-4 contract.

The collision probability method is the basic tool used in PROCELLA-3 to solve the neutron transport problem in the lattice cell. Let the cell be represented by N homogeneous regions in space and by G groups in energy. Then, for isotropic source and scattering in the laboratory system of coordinates, the neutron transport equation can be transformed into the set of collision probability equations [6, 7]

$$V_i \Sigma_i^g \Phi_i^g = \sum_{j=1}^{N} V_j P^g_{j \to i} \left(\sum_{h=1}^{G} C_j^{h \to g} \Sigma_j^h \Phi_j^h + Q_j^g \right) \quad (1)$$

$$(i = 1, \ldots, N; \quad g = 1, \ldots, G)$$

to be solved for the region-averaged group-integrated fluxes. The symbol $P^g_{j \to i}$ denotes the average probability that a neutron born in volume V_j with energy in group g will make its first collision in volume V_i, and the symbol $C_j^{h \to g}$ denotes the average number of neutrons with energy in group g produced in volume V_j per one neutron first-colliding there with energy in group h.

The PROCELLA-3 code solves eqs. (1) either in the continuous-energy two-region (slowing-down and thermalization), or in the few-group multi-region (space distribution of thermal neutrons, fast fission factor) approximation.

2 FEATURES OF « PROCELLA-3 »

2.1 CELL GEOMETRY AND COMPOSITION

The cell geometry considered in PROCELLA-3 is sketched in fig. 1: the fuel is in the form of rods or tubes, arranged either in single rod or in cluster lattice, allowance being made for the central rod to be missing. Outside the very fuel element, one or more concentric annular regions are present, the last one being the true moderator region.

With reference to fig. 1, the following comments are in order:

— the calculation of effective resonance surface, resonance escape probability and fast fission factor considers the « fuel » (containing up to five different compositions) region to cover the radius OA, while all other materials are diluted in a single « moderator » region, having thickness AE;

— thermal spectrum and diffusion coefficients are calculated by dividing the cell into three regions: fuel (radius OB), void (thickness BC), and moderator (thickness CE);

— consistent parameters for the homogenized cell are evaluated by a two-region (« channel » and « moderator ») description of the cell, the « channel » radius extending up to the inner radius OD of the true moderator (thickness DE).

Up to five different compositions may characterize the clustered region, whereas new compositions must be assigned to the remaining annular regions. Such compositions are obtained by combining the nuclides listed in tab. 1.

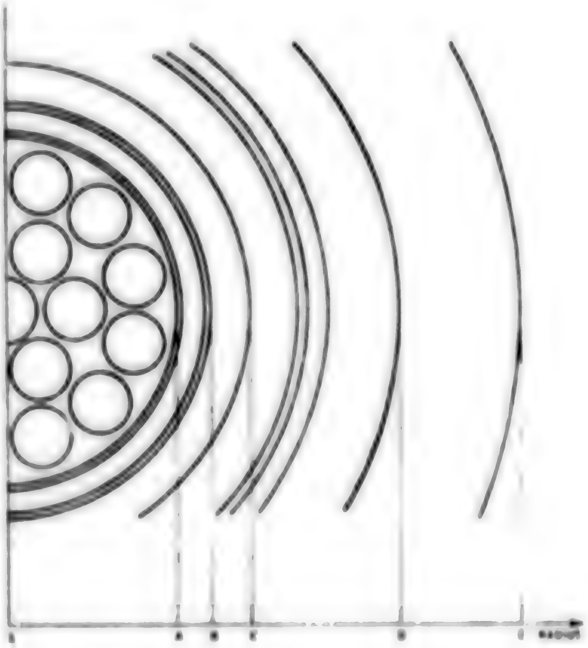

Fig. 1 - Cell geometry in PROCELLA-3.

TABLE 1

NUCLIDES IN THE NUCLEAR LIBRARY OF PROCELLA-3

Identification number	Nuclide	Identification number	Nuclide
1	^{235}U	21	Ps-fp-45
2	^{239}Pu	22	Ps-fp-19
3	^{240}Pu	23	Ps-fp-29
4	^{241}Pu	24	Ps-fp-39
5	^{238}U	25	Ps-fp-49
6	H_2O	26	^{149}Sm
7	D_2O	27	^{151}Sm
8	H	28	^{157}Gd
9	O	29	^{155}Eu
10	Zircaloy-2	30	^{113}Cd
11	^{236}U	31	^{232}Th
12	C	32	^{233}Pa
13	Al	33	^{233}U
14	B	34	^{234}U
15	^{135}Xe	35	Ps-fp-13
16	^{242}Pu	36	Ps-fp-23
17	^{241}Am	37	Ps-fp-33
18	Ps-fp-15	38	Ps-fp-43
19	Ps-fp-25	39	(free)
20	Ps-fp-35	40	(free)

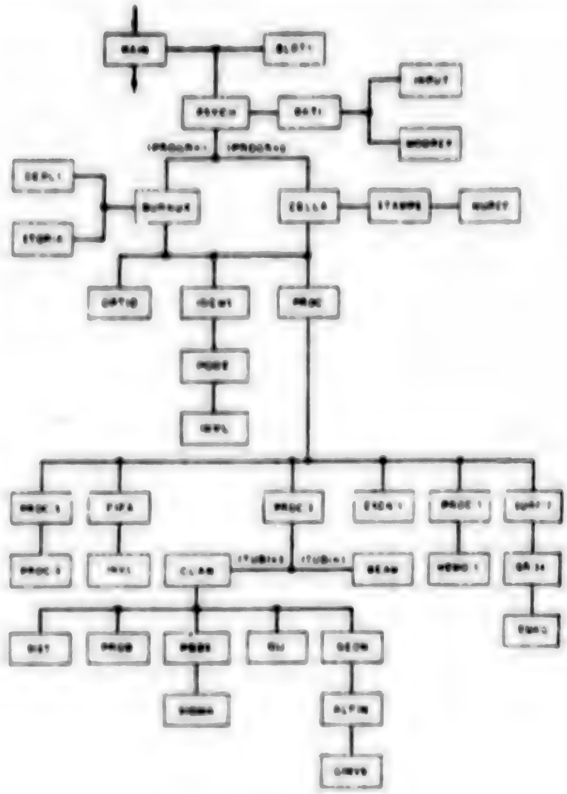

Fig. 2 - Logical flow of PROCELLA-3

2.2. STRUCTURE AND OUTPUTS OF «PROCELLA-3»

The code modules are so ordered that the overall calculation is sequential and each phase of the physics calculation starts with the proper cell homogenization ready. The logical flow of PROCELLA-3 computations is given in fig. 2.
The main output items are:

— cell parameters ε, p, η, f, k_∞, M^2, B^2_m;

— two-group cell parameters (macroscopic cross sections Σ and diffusion coefficients D) for core analysis codes, tabulated and punched as functions of irradiation, fuel temperature, instantaneous and irradiation-weighted coolant density, Xe and Rh concentrations;

— cell-averaged macroscopic cross sections and diffusion coefficients for 1 through 4 energy groups;

— buckling-dependent quantities, e.g. k_{eff}, I.C.R., spectral indexes, fission ratios;

— reactivity coefficients due to changes in temperature, coolant density, xenon concentration;

— irradiation - dependent nuclear densities in the fuel.

3. LATTICE PHYSICS

3.1. BASIC REQUIREMENTS

Reactor physics requirements can be summarized as follows:

— accurate prediction of both integral and detailed

parameters in all conditions, from a cold clean lattice to a hot irradiated one;

- fast calculations, suitable for parametric surveys;

- possibility of a simple physical interpretation of the results;

- no use of correlations, except for small adjustments.

The main problems to be solved in this perspective are spectral problems, such as those appearing in the resonance absorption and thermalization calculations. Integral rather than differential formulations are used (but for age theory below 0.1 MeV describing the high energy peaking in the fuel), i.e. first-collision probabilities for migration and exact or simplified integral scattering kernel for spectral problems.

3.2. ENERGY GROUP STRUCTURE AND CELL DIFFUSION EQUATIONS

The basic idea of the PROCELLA model is to separate out four broad energy groups, from the very beginning of the calculation, and to solve spectral problems within each of the broad groups by analytical or semi analytical models tailored on the particular needs of the group considered.

The space and energy distribution of thermal neutrons is found under the usual separability approximation, by solving the two simpler problems of determining the spectrum in the fuel-moderator two-region scheme of the cell and determining the space distribution of one-group neutrons, where cross sections are energy-averaged over the thermal range of the spectrum.

The four-group structure and its main items are given in tab. 2. The 4-group diffusion equations in the equivalent homogeneous cell are properly collapsed and the corresponding two-group (fast and thermal) diffusion equations

$$- D_1 \nabla^2 \Phi_1 + \Sigma_1 \Phi_1 = (\Sigma_{f1} \Phi_1 + \Sigma_{f2} \Phi_2)/k \qquad (2)$$

$$- D_2 \nabla^2 \Phi_2 + \Sigma_2 \Phi_2 = \Sigma_{21} \Phi_1 \qquad (3)$$

are adopted for whole-reactor calculations.

3.3. EFFECTIVE RESONANCE INTEGRAL

The effective resonance integrals of ^{238}U and ^{232}Th in the fuel element are assumed to have the form

$$I_{eff}(T) = (A + B\sqrt{S_{eff}/M}) \cdot [1 + \gamma(\sqrt{T} - \sqrt{T_0})] \qquad (4)$$

which depends on the fuel temperature T. In eq. (4) A is the mass absorption constant and the surface contribution contains the effective resonance surface S_{eff} [8, 9, 10, 11], the fuel material mass M and the experimental constant B.

The total resonance absorption rate A_a is related to the effective resonance integral by the equation

$$A_a = N_a V_a \Phi_0 I_{eff} \qquad (5)$$

TABLE 2

THE FOUR-GROUP ENERGY STRUCTURE OF PROCELLA-3

Group	Upper energy	Upper lethargy	Main events
Fast	2.0 MeV	0.0	Calculation of fast fission factor ε
Resonance	0.1 MeV	3.0	Calculation of resonance escape probability p accounting for ^{238}U and ^{232}Th resonance absorption
Epithermal	5 eV	12.9	Self-shielded absorption and fission, ^{240}Pu resonance absorption
Thermal (*)	$\mu k\vartheta_m$	Δu_m	Calculation of thermal flux spatial distribution and related quantities η, f

(*) $\mu k\vartheta_m$ = Westcott cut-off energy (eV) in the moderator, where the neutron temperature is ϑ_m.
$\Delta u_m = \ln(2 \cdot 10^6 / \mu k\vartheta_m)$

where V_e and N_e are volume and number density of the resonance absorber relevant to the fuel material, and Φ_0 is the constant flux per unit lethargy.

3.4. THERMALIZATION MODEL

A continuous-energy two-region, fuel and moderator, description of the cell is assumed. The average spectrum in the moderator is described [12, 13] by the Westcott expression

$$\Phi_m(E) = M(E, \vartheta_m) + \frac{a}{E}\,\Delta_c\left(\frac{E}{k\,\vartheta_m}\right) \tag{6}$$

where $M(E, \vartheta) = E \exp(-E/k\,\vartheta)/(k\,\vartheta)^2$ is the Maxwellian distribution and ϑ_m is the neutron kinetic temperature of the moderator.

The spatially averaged spectrum in the fuel region results from the superposition of a thermal and an epithermal solution to a two-region balance equation, and writes

$$\Phi_1(E) = \frac{M(E, \vartheta_m) + w\,M(E, T_1)}{1 + \mu\,[\Sigma_a(E) + \xi\,\Sigma_s]_{fuel}} + \frac{a}{E}\,\Delta_c\left(\frac{E}{k\,\vartheta_m}\right) \chi(E) \tag{7}$$

where T_1 is the $(\xi\,\Sigma_s V)$ - weighted physical temperature of the fuel element, μ is related to the self-collision probability P_{11} in the fuel element and to the neutron incurrent y_0 from the moderator, w accounts for re-thermalization in the fuel element and is proportional to $\mu\,(\xi\,\Sigma_s)_{fuel}$, $\chi(E)$ is an epithermal disadvantage factor having average value χ_e. The thermal equation is

$$\begin{aligned}
\Sigma_1(E)\,\Phi_1(E) = \\
&= \breve{P}_{11}(E) \int \Sigma_{s1}(E' \to E)\,\Phi_1(E')\,dE' + \\
&+ 4\,y_0(E)\,\Sigma_1(E)\,[1 - P_{11}(E)]
\end{aligned} \tag{8}$$

where P_{11} and $\breve{P}_{11}$ are the fuel self-collision probability with flat and parabolic scattering source respectively, and is solved by using the « amnesia » kernel

$$\begin{aligned}
\Sigma_{s1}(E' \to E) = {} & [\xi_1\,M(E', T_1) + \\
&+ (1 - \xi_1)\,\delta(E' - E)]\,\Sigma_{s1}(E')
\end{aligned} \tag{9}$$

ξ_1 being an appropriate parameter related to the scatterer mass. Instead, an equivalence principle [13] transforms the epithermal neutron balance equation into an equation related to proper non-moderating fuel elements.

The formalism adopted has the advantage of permitting a direct utilization of Westcott's tabulations. The thermal and epithermal Westcott-type absorption and fission cross sections are given by

$$\sigma_M = \sigma_0\,g(\vartheta) \tag{10}$$

where g comes from Westcott's compilation, except for ^{239}Pu [12], and ϑ is the properly defined kinetic neutron temperature in the region, and

$$\sigma_e = \{\sigma_M + \sigma_0\,s(\vartheta_m)\,\chi_R/(b\,\chi_e)\}/\Delta u_m \tag{11}$$

where s comes from Westcott's compilation, $\chi_R = \chi_e = 1$ in the moderator region, χ_R is an average shielding factor to be used for ^{238}U and Plutonia only.

In addition, the thermal spectrum is assumed to vary quadratically [14] inside the fuel region, so allowing for a position-dependent neutron temperature of the fuel element.

3.5. SPATIAL FLUX DISTRIBUTION

The spatial distribution of thermal neutrons can be obtained either by an ABG annular system method [2], with ring-by-ring homogenization of clustered fuel elements (and relying on flat-flux collision probabilities and near-isotropic interface fluxes), or by an analytical method [5], devised for clustered fuel elements. The cluster is divided into subcells, each containing one fuel rod and some associated coolant, and arranged on rings. A subcell collision probability G is defined for one neutron entering isotropically the subcell surface. By the requirement

$$G = 2\,\Sigma^*\,R_B\,[1 - P_c(\Sigma^*\,R_e)] \tag{12}$$

where R_B = subcell black radius, R_e = subcell equivalent radius, $P_c(x)$ = self-collision probability for a cylinder of optical radius x, the subcell-homogenized cross section Σ^* is obtained and attributed to the proper ring (where the subcell has been ar-

ranged). Now the usual formulas for collision probabilities in a cell of concentric rings may be used. For neutrons colliding in any ring, the fraction colliding in the rods is assumed to depend on the ring properties only, and then the thermal utilization can be calculated by a simple rule.
The group diffusion coefficients are calculated specializing the Benoist's theory to a three-region (fuel, void, moderator) cell [2].

3.6. RESONANCE ESCAPE PROBABILITY

The resonance escape probability is so defined [15] that the product εp represents the number of neutrons being thermalized if only resonance absorption in either ^{238}U or ^{232}Th occurs during slowing-down. It is given by

$$p = \exp\left[-N_a V_a (I_{eff} + \Delta I_{eff}) / (\xi \Sigma_s V)_{cell}\right] \qquad (13)$$

where I_{eff} is the absorber (nuclear density N_a, volume V_a) effective resonance integral in a $1/E$ spectrum and

$$\Delta I_{eff} = \int (\Phi_{fuel}/\Phi_{cell} - 1)\, \sigma_{a0}(u)\, du \qquad (14)$$

represents the excess integral due to flux peaking and resonance shadowing.

3.7. FAST FISSION FACTOR

The fast fission factor is defined [16] as the number of neutrons being slowed-down past 0.1 MeV per one neutron born from fissions below 0.1 MeV in an infinite-lattice cell.
Defining the three groups of neutrons 0 (with energy above the fission threshold), 1 (with energy between the fission threshold and 0.1 MeV), 2 (with energy below 0.1 MeV), the above definition yields

$$\varepsilon = f^0 + \gamma^0 + \sum_i \left((\Sigma\Phi)^1_i c_i^{1\to 0} + (\Sigma\Phi)^2_i c_i^{2\to 0} \right) \qquad (15)$$

where i stands for fuel, coolant, moderator; f^g is the fraction of fission neutrons born in group g, γ^g is the fraction of photoneutrons born in group g in the moderator and $c_i^{h\to g}$ is the number of secondary neutrons per collision (including scattering, fission multiplication, $n\,2n$ reactions).
The group collision densities are normalized to one non-fast fission neutron per second in the cell and solve the system

$$(\Sigma\Phi)^g_i = f^g \tilde{P}^g_{fuel\to i} + \gamma^g P^g_{mod\to i} + \sum_j \left((\Sigma\Phi)^1_j c_j^{1\to g} + (\Sigma\Phi)^2_j c_j^{2\to g} \right) P^g_{j\to i} \qquad (16)$$

(i = fuel, coolant, moderator; g = 1, 2)

The P's are the usual flat-flux collision probabilities, whereas the $\tilde{P}$'s are calculated for a parabolic thermal flux distribution over the whole fuel element, from its disadvantage factor as evaluated in the thermal group calculation, and by using very accurate approximations to the special functions involved [17].

3.8. FUEL BURN-UP EQUATIONS

Long-term irradiation changes in the lattice cell are evaluated by considering [4, 5] the heavy isotopes chains

$$^{238}U \to {}^{239}Np \to {}^{239}Pu \to {}^{240}Pu \to {}^{241}Pu \qquad (17)$$

$$^{232}Th \to {}^{233}Pa \to {}^{233}U \to {}^{234}U \to {}^{235}U \qquad (18)$$

for fertile-to-fissile transformation, the burn-up of ^{235}U and the production of fission products (^{135}Xe, ^{149}Sm, ^{151}Sm, ^{157}Gd, ^{155}Eu, ^{113}Cd; four pseudo-fission-products per fissile, lumping low cross section nuclides). That evaluation requires to solve a system of ordinary differential equations like

$$dN/dt = S - (\sigma\Phi + \lambda) N \qquad (19)$$

where Φ is the Westcott flux in the fuel.
In order to account for space-dependent burn-up, isotopic changes are determined by solving eqs. (19) for each fuelled annular region in the cell.

4. PREDICTIONS OF « PROCELLA-3 »

4.1. TESTS ON CLEAN LATTICES

The accuracy of PROCELLA-3 predictions has been assessed by comparing theory vs. experiments for D_2O lattices.
Tab. 3 summarizes the results on material buckling

TABLE 3

OVERALL CHECK CALCULATIONS BASED ON BUCKLING MEASUREMENTS

Type of lattice	U rods	7-rod U clusters	19-rod U clusters	UO_2 small clusters	UO_2 large clusters	UC clusters
Number of lattices	53	22	16	28	76	8
$k_{eff,\ avg}$	1.0008	1.0029	0.9948	1.0068	1.0032	1.0064
d	0.0045	0.0069	0.0026	0.0043	0.0060	0.0058
Percentage number of lattices having $[k_{eff}(B^2) - k_{eff,\ avg}]$ within $\pm d$	81.1	86.4	75.0	71.4	71.1	75.0
$\pm 2d$	98.2	95.5	93.7	89.3	92.1	87.5

measurements (e.g. on critical assemblies): the calculated k_{eff} (which would be unity for perfect theory and experiment) represents a good index of the overall reliability of the model.

The data, mostly taken from the open literature, are classified in separate sets according to the basic characteristics of the lattices, such as metal rods, metal clusters, oxide clusters. Most data are relevant to natural uranium fuel, a few ones to slightly enriched uranium.

For each set, assumed to include N points, the average effective multiplication constant

$$k_{eff,\ avg} = \frac{1}{N} \sum_{n=1}^{N} k_{eff,\ n} \tag{37}$$

TABLE 4

VALUES OF k_∞ FOR UO_2 19-ROD CLUSTERS

Coolant	Lattice pitch (cm)	Experiment	PROCELLA	PROCELLA-3
D_2O	17.8	1.005	0.999	1.006
	20.3	1.052	1.045	1.051
	22.8	1.088	1.072	1.077
Air	17.8	1.011	1.003	1.009
	20.3	1.061	1.054	1.060
	22.8	1.110	1.083	1.096

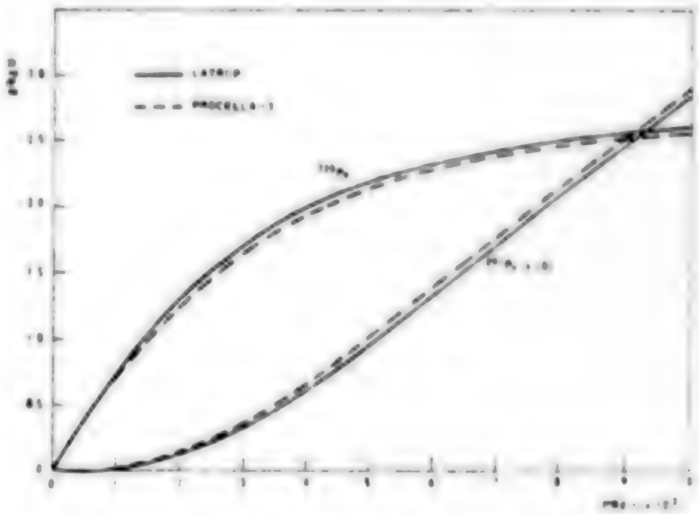

Fig. 3 - Predicted ^{239}Pu and ^{241}Pu contents in irradiated NPD lattices.

and its standard deviation

$$d = \frac{1}{\sqrt{N-1}} \left(\sum_{n=1}^{N} (k_{eff,\ n} - k_{eff,\ avg})^2 \right)^{1/2} \tag{38}$$

are given. In case of random experimental errors one would expect to get 68.3% of the calculated k_{eff} within $\pm d$ and 95.4% within $\pm 2d$, with respect to the average value eq. (37).

The following comments can be made to tab. 3:

— in every type of lattices the average effective multiplication is very close to unity, the standard deviation being of the order of experimental errors, thus well within the limits of accuracy exhibited by far more complicated multi-group calculations;

TABLE 5

NEUTRON DENSITY (NORMALIZED TO UNITY IN THE MODERATOR) FOR ThO_2-UO_2 19-ROD CLUSTERS (*)

Coolant	Lattice pitch (cm)	Experiment	LATREP	PROCELLA-3
Air	22	0.399/0.420/0.510	0.347/0.390/0.508	0.376/0.399/0.490
	28	0.349/0.378/0.467	0.310/0.330/0.460	0.332/0.354/0.439
D_2O	22	0.348/0.383/0.510	0.315/0.357/0.486	0.349/0.377/0.485
	28	0.314/0.335/0.467	0.270/0.320/0.443	0.306/0.332/0.434
H_2O	22	0.230/0.268/0.436	0.248/0.288/0.447	0.290/0.340/0.400
	28	0.208/0.245/0.393	0.204/0.242/0.397	0.248/0.288/0.413
Organic	22	0.252/0.290/0.449	0.255/0.297/0.453	0.290/0.340/0.470
	28	0.208/0.246/0.394	0.214/0.253/0.405	0.248/0.288/0.415

(*) Center rod/6 rod middle annulus/12 rod outer annulus.

TABLE 6

DATA FROM IRRADIATION OF NPD BUNDLES

	Experiment	LATREP	PROCELLA-3	Experiment	LATREP	PROCELLA-3
Burnup (MWd/t)		~ 6 000			~ 10 000	
^{235}U/initial ^{235}U		0.3905			0.2088	
^{236}U/^{235}U		0.00285			0.00151	
Pu/U	0.00312	0.00323	0.00312	0.00433	0.00434	0.00429
^{239}Pu/Pu	0.7334	0.7336	0.7246	0.6195	0.6145	0.6040
^{240}Pu/Pu	0.2204	0.2201	0.2290	0.2980	0.3024	0.3085
^{241}Pu/Pu	[illegible]	[illegible]	[illegible]	0.0386	0.0388	0.0409

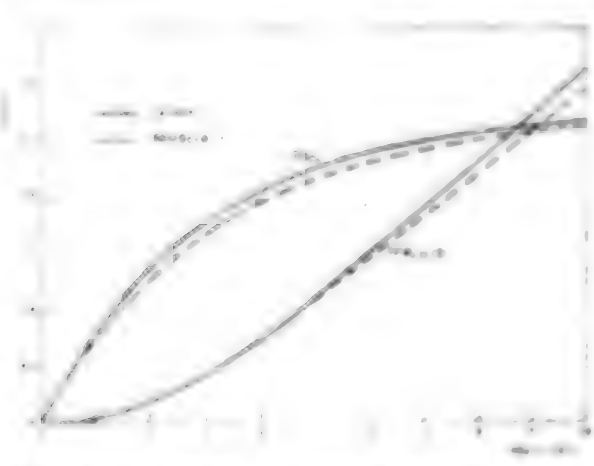

Fig. 4 - Predicted ^{239}Pu and ^{241}Pu contents in irradiated CANDU-PHW lattices

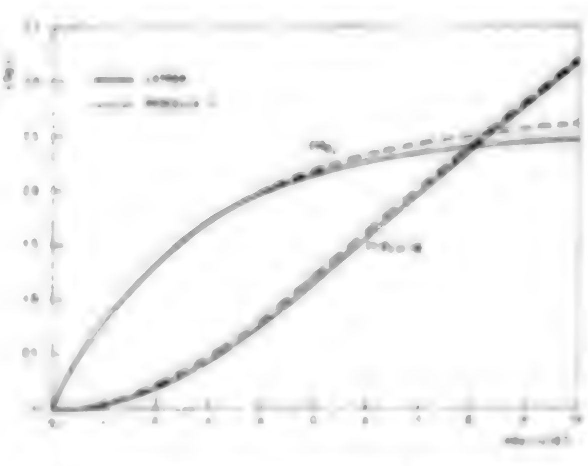

Fig. 5 - Predicted ^{239}Pu and ^{241}Pu contents in irradiated CANDU-BLW lattices

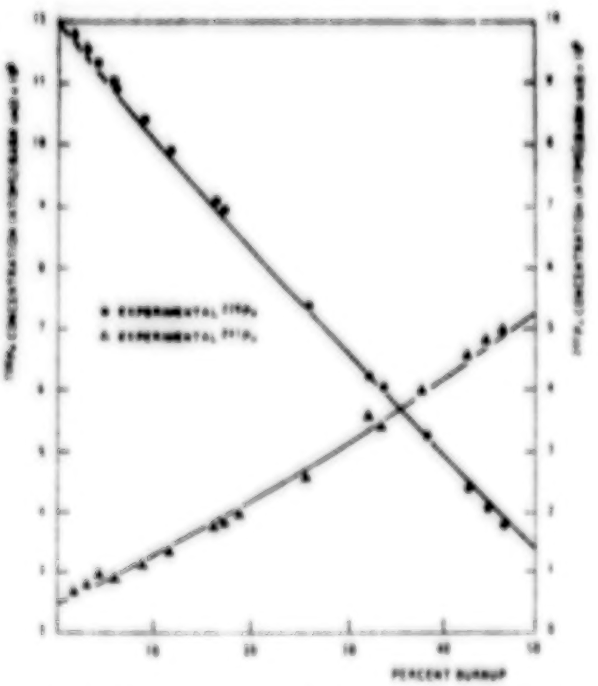

Fig. 6 - Isotopic concentrations for fuel in the center rod of a Pu-Al cluster.

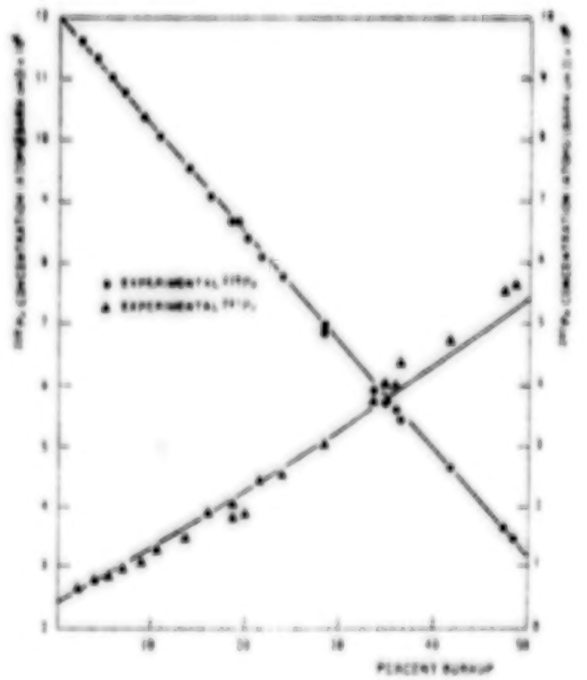

Fig. 8 - Isotopic concentrations for fuel in the outer ring of a Pu-Al cluster.

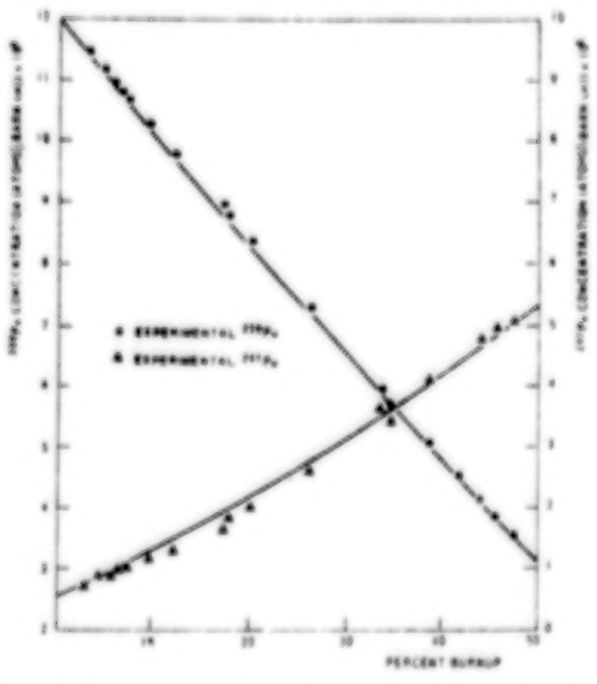

Fig. 7 - Isotopic concentrations for fuel in the middle ring of a Pu-Al cluster.

— the dispersion of the calculated data points corresponds very nearly to a Gaussian distribution; since no uncertainty is accounted for in the k_{eff} calculation, the dispersion of data is partially due to the experimental errors;

— no significant trend of k_{eff} vs. the moderator-to-fuel volume ratio was ever found;

— sometimes, some systematic difference was found in data from different source experiments.

An interesting overall check of the theory is also provided by comparison of calculated and measured [18] values of the infinite multiplication constant: tab. 4 summarizes some satisfactory results obtained. The detailed thermal neutron distribution in ThO_2-UO_2 19-rod clusters is reported in tab.5, where measured [19] and calculated values are given for different coolant materials and lattice pitches.

4.2. TESTS ON IRRADIATED LATTICES

The burn-up option of PROCELLA-3 has been satisfactory checked against both experimental and calculated data on irradiated fuel.

TABLE 7

VALUES OF k_∞ FOR CIRENE 19-ROD CLUSTERS (27 cm SQUARE LATTICE PITCH, 20 °C)

^{235}U (w/o)	H_2O (g/cm³)	Experiment (± 0.005)	MC (± 0.005)	PROCELLA-3
0.71	0.0	1.157	1.157	1.148
0.91		1.262	1.248	1.254
1.00		1.298	1.286	1.292
1.15		1.375	1.341	1.346
0.71	0.33	1.118	1.108	1.110
0.91		1.222	1.207	1.216
1.00		1.261	1.255	1.254
1.15		1.335	1.303	1.309

Tab. 6 compares measured and predicted compositions of NPD bundles [19] irradiated up to approximately 6000 and 10 000 MWd/t. In order to provide a sound calibration, all values were normalized to the same ^{235}U content; experimental data are given vs. LATREP [20, 21] and PROCELLA-3 calculations.

Figs. 3÷5 report the ^{239}Pu and ^{241}Pu contents predicted by LATREP [22] and PROCELLA-3 for irradiated NPD, CANDU-PHW, and CANDU-BLW lattices.

TABLE 8

VALUES OF k_∞ AND f FOR CIRENE 18-ROD CLUSTERS (27 cm SQUARE LATTICE PITCH, 20 °C)

H_2O density (g/cm³)		Infinite multiplication		Thermal utilization	
Cluster	Center rod	Experiment	PROCELLA-3	Experiment	PROCELLA-3
0.0	0.0	1.157	1.151	0.955	0.956
	0.47	1.151	1.146	0.953	0.954
	0.73	1.150	1.144	0.951	0.952
0.33	0.0	1.114	1.112	0.922	0.927
	0.47	1.111	1.108	0.921	0.925
	0.73	1.112	1.106	0.920	0.923

Figs. 6÷8 give the Pu contents as functions of irradiation in the fuelled annuli of a Pu-Al 19-rod cluster [23].

4.3. TESTS ON CIRENE FUEL ELEMENTS

PROCELLA-3 predictions for CIRENE fuel elements were checked vs. both measurements and different calculations.

Tab. 7 reports k_∞ values [24, 25, 26] relevant to variously enriched CIRENE 19-rod clusters, voided and average coolant density channels, obtained by experiments, Montecarlo and PROCELLA-3 calculations. Tab. 8 gives values [24, 25, 26] of k_∞ and f for CIRENE 18-rod clusters in various coolant conditions, as obtained by experiments and PROCELLA-3 calculations.

Manuscript received April 15, 1980

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CSO: 5100

SWEDEN

BRIEFS

FORSMARK-2 NUCLEAR PLANT LOADED--The loading of Forsmark 2, Sweden's ninth nuclear reactor, began on Monday night. It will take up to 3 weeks before all 676 fuel elements have been placed in the reactor tank and the pilot operation can begin. Commercial operation will begin in August 1981. The seventh reactor--Forsmark 1--is undergoing its final tests now, and commercial operation will begin about 1 January. This was announced by the State Power Board, which is the largest stockholder in the Forsmark power group. Together, Forsmark 1 and 2 will produce about 11 GWh (billion kilowatt-hours) per year. Sweden's total electricity consumption stands at about 95 GWh this year. The eighth reactor--Ringhals 3--is also in pilot operation and is expected to be ready for commercial operation beginning in February. It is expected to produce about 5.5 GWh per year. The State Power Board points out that the power from nuclear powerplants is cheap. Electric power from Forsmark costs about 13 ore per kilowatt-hour. That includes a portion of the future cost of final storage for high-level waste. The 10th reactor is Ringhals 4, and it will be loaded with nuclear fuel in 1982. That will leave only Forsmark 3 and Oskarshamn 3, both of which will go into operation in the mid-1980's. About 35 GWh per year will be produced by those six new nuclear reactors. The six old reactors provide 22.5 GWh per year. According to several estimates, the startup of the six new reactors will provide a surplus of power throughout the 1980's. The power companies want to use that surplus for heating, which of course will reduce our dependence on oil. One way to do that would be to install electric boilers in central hot-water plants. [Text] [Stockholm DAGENS NYHETER in Swedish 5 Nov 80 p 13] 11798

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